Before discussing the claims and how they distinguish over the cited art, perhaps it might be helpful to review features of applicant's invention.

Applicants' invention relates to strain compensation. As described, with Applicant's invention the Schottky layer and the channel layer are oppositely strained. This is accomplished using materials having selected **compositions**.

More particularly, as set forth in the patent application:

> In another embodiment of the invention, referring now to FIG. 5, a double recessed, strain compensated HEMT is provided. The HEMT 100 includes a semi-insulating, single crystal InP substrate 102. The substrate 102 has an inherent lattice constant. Disposed above the substrate 102 is an undoped buffer layer 104 lattice matched to the substrate 102.
>
> The buffer layer 104 here is $Al_{0.48}In_{0.52}As$, having a thickness of 1,500-5,000 $\mathring{A}$, typically about 2000 $\mathring{A}$. Disposed above the buffer layer 104 is a first pulse layer 106, also called δ-doped or pulse doped layer. The pulse layer 106 is silicon and has a doping concentration of $0.5x10^{12}$-$2x10^{12}$ cm^{-2}, typically $lxl0^{x12}$ cm^{-2} Disposed above the first pulse layer 106 is a first spacer layer 108. The first spacer layer 108 is $Al_{048}In_{0.52}As$, having a thickness of 30-50 $\mathring{A}$, preferably about 50 $\mathring{A}$ thick, and undoped.
>
> Disposed over the first spacer layer 108 is the channel layer 110 having an inherent lattice constant. ***The lattice constant of the channel layer 110 is different than the lattice constant of the substrate 102. The channel layer 110 serves as a strain compensation layer, comprised of a material which will develop an inherent or intrinsic compressive strain when grown over the first spacer layer 108 due to lattice constant mismatch between the channel layer 110 and the substrate 102. Here, the material used for the channel layer 110 is $Ga_{1-x}In_xA_s$, with an indium concentration, x, of 0.53-0.70, preferably 0.60-0.65***. The channel layer 110 has a thickness of 50-400 $\mathring{A}$, preferably about 200 $\mathring{A}$ thick, and is undoped. ***The thickness of the channel layer 110 is a function of the indium concentration in the channel layer 110, since the indium concentration in the channel layer 110 affects the lattice constant (and strain) of the channel layer 110. As the indium concentration changes, the lattice constant of the channel layer also changes, thereby affecting the degree of lattice mismatch between the channel layer 110 and other layers in the HEMT 100. The greater the lattice mismatch, the thinner the channel layer 110 will be to avoid dislocations in the channel layer 110. In general, the composition and thickness of the channel layer 110 is selected to provide a layer having an intrinsic compressive stress which substantially compensates for intrinsic tensile stress of a Schottky layer 116 disposed over the channel layer 110, as***

described below. The thickness and indium concentration of the channel layer 110 are selected to maximize that compensating effect while avoiding dislocations in the channel layer 110, and consequently do not exceed the elastic strain limits of the channel layer 110.

First, disposed above the channel layer 110 is a second spacer layer 312. The second spacer layer 112 here is $Al_{0.48}In_{0.52}As$, about 30-50 $\mathring{A}$ thick, and undoped. Disposed above the second spacer layer 112 is a second pulse layer 114, also called a δ-doped or pulse doped layer. The second pulse layer 114 is silicon and has a doping concentration of about $2x10^{12}$-$4x10^{12}$ cm^{-2}, preferably $3x10^{12}$ cm^{-2}, typically providing a ratio of doping concentrations between the first pulse layer 106 and the second pulse layer 114 of approximately 2.5 to 1.5 to help linearize performance of the transistor 100.

Disposed above the second pulse layer 114 is the Schottky layer 116 having an inherent lattice constant. ***The lattice constant of the Schottky layer 116 is different than the lattice constants of the channel layer 110 and of the substrate 102. That is, these three layers are not lattice matched. Typically, the lattice constant of the Schottky layer 116 is smaller than the lattice constant of the substrate 102, and the lattice constant of the channel layer 110 is larger than the lattice constant of the substrate 102. Here, the Schottky layer 116 is $Al_{1-x}In_xAs$ with an aluminum concentration, 1-x, of 0.55-0.65, preferably 0.60.*** The Schottky layer 116 has a thickness of 50-400 $\mathring{A}$, preferably about 200 $\mathring{A}$ thick, and is undoped. The thickness of the Schottky layer 116 will depend on the indium concentration in the Schottky layer 116. ***As the indium concentration changes, the lattice constant (and strain) of the Schottky layer also changes. Similar to the channel layer 110, the thickness and indium concentration of the Schottky layer 116 are balanced and maximized while avoiding dislocations due to lattice mismatch.*** Here, the Schottky layer 116 is undoped. An undoped Schottky layer provides a higher breakdown voltage than with a doped Schottky layer. A doped Schottky layer reduces resistance which lowers the breakdown voltage and increases conduction compared to an undoped Schottky layer. The growth of the Schottky layer provides a layer having tensile strain due to the lattice mismatch between the Schottky layer 116 and the underlying layers.

By disposing the channel or strain compensation layer 110 between the buffer layer 104 and the Schottky layer 116, the Schottky layer 116 may be grown to a larger thickness than if the Schottky layer 116 were grown directly on the buffer layer 104. Alternatively, the aluminum concentration in the Schottky layer 116 may be increased or any combination of the aforementioned arrangements may be provided to form the Schottky layer. Insertion of the channel layer 110 permits a thicker Schottky layer 116 or alternatively a higher concentration of aluminum in said Schottky layer 116

before the Schottky layer 116 reaches a sufficiently high enough tensile strain to cause dislocations in the crystal lattice of said Schottky layer 116. With the above arrangement, the channel layer 110 is grown to a thickness approaching, but not exceeding, a critical thickness of the channel layer 110. The Schottky layer 116 is grown over the channel layer 110. ***The initial growth of the Schottky layer 116 would provide a layer having tensile strain which would be compensated for by the compressive strains in the underlying channel layer 110. After the Schottky layer 116 is grown to a first thickness of zero net strain (i.e. compensated for by the compressive strain of the channel layer), the Schottky layer 116 is grown to an additional thickness until the Schottky layer additional thickness reaches a so-called critical thickness of the layer. By either incorporating additional aluminum into the Schottky layer 116 or by increasing the thickness of the Schottky layer 116, a higher bandgap for breakdown is achieved. Similarly, the tensile strain in the Schottky layer 116 stabilizes the high indium concentration in the channel layer 110. High indium concentration permits higher electron mobility and higher electron saturation velocity, thereby improving the overall performance of the HEMT 100 and permitting the HEMT 100 to handle larger amount of currents and thus power at higher frequencies. Further, an increase in aluminum concentration in the Schottky layer 116 and/or a higher indium concentration in the channel layer 110 increases the conduction band discontinuity between the Schottky 116 and channel 110 layers. This increases the current sheet density which also improves power performance.*** (emphasis added)

The Applicant shows in the patent application results of using this strain compensation. More particularly, as stated in the patent application:

The strain compensated, double recessed HEMT 100 shown in FIG. 5 has been fabricated and tested. The tensile strain in the Schottky layer 116 is compensated by the compressive strain in the channel layer 110. This strain compensation allows the Schottky layer 116 to be grown thicker or to be grown with higher aluminum concentration than if the Schottky layer were lattice matched with the underlying layers. The use of higher indium concentration in the channel layer 110, because of strain compensation in the Schottky layer 116, increases the unity current gain cutoff frequency. Because of the larger conduction band discontinuity between the Schottky 116 and channel 110 layers (than had the layers been lattice matched), high output currents are obtained, Low breakdown voltages from the high indium concentration in the channel layer 110 are alleviated by the use of a double recessed gate process. The transistor 100 exhibits high output current (690 - 850 mA/mm) and high breakdown voltages (9 -11 V) simultaneously. Due to the high indium concentration in the channel, the peak unity current gain

cutoff frequency approaches 200GHz and 160 GHz for devices with first recess widths of 0.8 im and 1.2 im, respectively. Typical carrier sheet density is $4x10^{12}$ cm^2 and Hall mobility is 9600 cm^2/V-sec at room temperature,

Referring now to the Office Action:

Claims 18-21, 23 and 31 stand rejected under 35 U. S. C. 102(e) as being anticipated by Onda et al.

The Examiner states that: "Onda does not teach the lattice constant of the schottky layer is smaller than the lattice constant of the substrate and the lattice constant of the channel layer is larger than the lattice constant of the substrate, this feature is inherent in Onda's device because the structure and materials of Onda's device are identical to the claimed structure."

Enclosed herewith is Figure 1.6 of a book entitled: Indium Phosphide and Related Materials:Processing, Technology, and Device; editor Avisay Katz, published 1992. Such Figure clearly shows that lattice constant of a material is a function of the ***COMPOSITION*** of the material. Nothing in Onda recognizes or suggests selecting the lattice mismatches claimed in the present application. The materials set forth in Onda will not have these mismatches since there is no designation in Onda of any specific ***COMPOSITION*** of the material to produce the claimed lattice constant mismatches. Nothing in Onda suggest having the claimed mismatch so there is nothing disclosed in Onda which leads one, or describes to one, or to put one in possession of the claimed invention which include these lattice mismatches

In summary, to obtain the claimed lattice mismatches requires one to use materials having specific ***COMPOSITIONS***-Onda gives neither specific ***COMPOSITIONS*** to produce the claimed lattice mismatches NOR does Onda suggest or indicate in any way that the materials are selected to produce the claimed lattice mismatches.

With regard to claim 31, the material set forth in such claim is disclosed in the material furnished with the declaration filed under 35 CFR 1.131.

In the event any additional fee is required, please charge such amount to Patent and Trademark Office Deposit Account No. 50-0845.

Respectfully submitted,

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Table 1.2
Calculated and Experimental Valence Band Offsets (eV) for GaAs, InP-Based Heterostructures as Compiled in Ruan and Ching [17]

Heterostructure	*Experiment*	*EAR*	*HAO*	*Tersoff's Model*	*Effective Dipole Model*[d]	*Total Energy Minimization*
Ge/InP	0.64	0.90	0.64	0.58	0.67	
Ge/GaAs	0.25–0.65	0.70	0.41	0.52	0.51	
Si/InP	0.57	0.58	0.24	0.40	0.36	
Si/GaAs	0.05	0.38	0.03	0.34	0.22	
GaAs/AlAs	0.19–0.50	0.52	0.04	0.35	0.36	
GaAs/InAs	0.17	0.19	0.32	0.20	0.16	
GaAs/ZnSe	0.96–1.10	1.31	1.05	—	0.95	
InP/CdS	1.63	1.40	1.36	—	0.97	
InSb/InP	—	0.87			0.71	
InSb/GaAs	—	0.67			0.53	
InAs/InP		0.39			0.29	
GaAs/InP	—	0.20			0.13	
$Ga_{0.47}In_{0.53}As$/InP	0.346 ± 0.01[a] 0.39[b]					0.41
$Al_{0.48}In_{0.52}As$/InP	0.36 0.46[c]					0.25
$Ga_{0.47}In_{0.53}As$/ $Al_{0.48}In_{0.52}As$	0.13, 0.20 0.21[e]					0.17

(a) D.V. Lang, *Heterojunction Band Discontinuities*, ed. F. Capasso and G. Margaritondo, Amsterdam: North-Holland, 1987, p. 377.
(b) S.R. Forrest, *Heterojunction Band Discontinuities*, ed. F. Capasso and G. Margaritondo, Amsterdam: North-Holland, 1987, p. 311.
(c) Compiled in Hybertson [19].
(d) Ruan and Ching [17].
(e) Hybertson [18,19].

1.6 ALLOY SEMICONDUCTORS

Let us consider two III-V compounds, AC and BC, which form a cation alloy: $A_xB_{1-x}C$ (e.g., $Ga_xIn_{1-x}As$). Similarly, compounds AC and AD form an anion alloy: AC_xD_{1-x} (e.g., $InAs_xP_{1-x}$). Mixed compounds of this type are called ternary alloys. If the two compounds do not share a cation or an anion, one gets a quaternary alloy: for example, $Ga_xIn_{1-x}As_y$.

Figure 1.6 shows the lattice parameter versus energy gap at room temperature

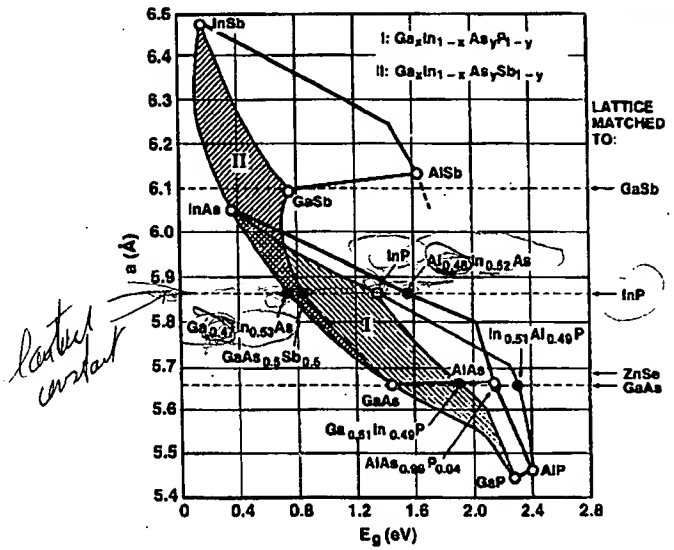

Figure 1.6 Lattice parameter *versus* energy gap at room temperature for various III-V compounds and their alloys [20].

for various III-V compounds and their alloys [20]. The figure also shows the composition of the lattice-matched ternary alloys and the corresponding substrates on which they are grown. The availability of good-quality substrates dictates to a large extent which of the lattice-matched heterostructures would be of use for device structures. At present, technologically important III-V heterostructures are limited to those grown on GaAs and InP substrates.

The shaded region I represents the quaternary alloy $Ga_xIn_{1-x}As_yP_{1-y}$, which can be grown lattice matched on GaAs or InP substrates. When GaAs is used as the substrate, the lattice-matched GaInAsP alloy covers the energy range 1.42–1.91 eV, more or less the same energy range as that covered by the ternary alloy AlGaAs. The GaInAsP alloy grown on InP substrate spans the energy range 0.75–1.35 eV between the bandgap of $Ga_{0.47}In_{0.53}As$ (0.75 eV) and that of InP (1.35 eV). The ternary alloy $Al_xIn_{1-x}As$ is lattice matched to InP at $x \sim 0.48$ and has a direct energy gap of 1.45 eV at room temperature. The $Al_xGa_yIn_{1-x-y}As$ alloy covers the spectral range 0.75–1.45 eV and is lattice matched in InP substrate for $x + y\ 1 \sim 0.47$. This alloy, containing only one group V atom, covers a wider spectral range than $Ga_xIn_{1-x}As_yP_{1-y}$ and may be advantageous for many heterostructure devices.